# TECHNICAL MEMORANDUM

# DEVELOPMENT OF VEHICLE SPEED PARAMETERS FOR ATLANTA NON-ATTAINMENT AREA EMISSIONS POST-PROCESSOR USED IN 2004 STATE IMPLEMENTATION PLAN

During the fall of 2000, the Georgia Regional Transportation Authority (GRTA) and its partners undertook a study of vehicle speeds on the Atlanta roadway network. This "speed study" was designed and conducted by Wilbur Smith Associates, a transportation-consulting firm, with oversight by GRTA in consultation with an interagency coordination group. The primary purpose of the study was to update vehicle speed information, and thus on-road mobile source emissions estimates, in the State Implementation Plan (SIP) for the Atlanta ozone non-attainment area.

Early in 2001, a data analysis team consisting of transportation and air quality professionals from Georgia Institute of Technology and Wilbur Smith Associates was formed and tasked with analyzing the data from this study and providing recommendations on using the results to improve estimates of vehicle speeds in Atlanta. This report summarizes the approach used by this analysis team.

## Approach

U.S. EPA's MOBILE-5b model requires a number of input parameters, including average vehicle speeds, in order to develop on-road mobile source emissions factors for regulatory purposes. In areas that have Travel Demand Models (TDMs), such as Atlanta, these average (space-mean) speeds are developed from model estimates of link volume (vehicles-per-hour) from the TDM. Since most of these models, including Atlanta's, are calibrated largely for volume estimates, the average vehicle speeds on the link are estimated from the link volumes by use of a separate post-processor that estimates how average vehicle speeds vary by facility type and lane-volume (vehicles-per-lane-per-hour).

In order to make these estimates, it is essential to estimate "free flow" speeds by facility and area type and to develop an understanding of how these speeds are reduced by lane volume and highway capacity. Measurements of "free flow" speeds require observations under conditions of low lane-volumes in the absence of congestion. Conversely, estimates of volume-related delay require observations at relatively high lane-volumes. The speed study was specifically designed with these considerations in mind and thus data were available for a variety of conditions.

## *Free Flow Speeds*

Free flow speeds are known to be a function of many parameters (e.g., geometric design, lane widths, traffic signal spacing and timing, number and spacing of curb cuts, frequency of vehicle maneuvers, etc.). Many, if not most, of these parameters are unavailable in the data streams from TDMs and thus surrogate variables are required (e.g., facility types, area types, speed limits).

### Facility and Area Types

Since the most important variables are related to facility type and the surrounding land use characteristics, the data analysis team examined numerous plots of observed vehicle speeds and lane-volumes to ascertain what groupings of facility and area types represented the best combinations for subsequent study. The facility and area types used in the analysis were those defined and used in the Atlanta Regional Commission's (ARC) TDM for Atlanta. The area classifications were the Central Business District (CBD) as well as Urban, Suburban, Exurban and Rural areas. The facility types considered were limited to those examined in the speed study and included Class I, II, and III Arterials, Collectors, and Freeways.

The determination of the area/facility combinations to be used in subsequent analyses was guided by both the statistical principles of minimization of variance and of economy of classification (i.e., new classifications should not be introduced unless they can be shown to be statistically different from existing classifications). Based on these analyses, nine groups of facility and area types were identified for independent analysis. These are:

- Freeways in CBD, Urban and Suburban areas
- Freeways in Exurban and Rural areas
- All Non-freeway facilities in CBD
- Arterial I in Urban and Suburban Areas
- Arterial I in Exurban and Rural Areas
- Arterial II and III in Urban and Suburban Areas
- Arterial II and III in Exurban and Rural Areas
- Urban and Suburban Collectors
- Exurban and Rural Collectors.

These classifications may be interpreted as accounting for, at least in a general way, the effects of highway capacity and adjacent land use on vehicle speeds. In other words, many of the factors that influence “free flow” speeds and highway capacity including lane width, traffic signal density and timing, frequency of turning maneuvers, pedestrian movements, and other factors tend, on average, to be more similar for two facilities belonging to one of the above classifications than they are for facilities belonging to two different classifications. Thus, analysis of the vehicle speed behavior of facilities by these classifications (that can be identified from the TDM) serves as a surrogate for the true independent variables that are not explicitly available from the TDM.

## Speed Limits

The speed study had previously concluded that both posted speed limit and traffic signal density were important factors for speed estimation. While the traffic signal density and a number of other factors were generalized by the grouping of facilities and areas described above, the team concluded that accounting for speed limit explicitly could significantly reduce uncertainties in speed estimates. To enable speed limit to be used as an explicit variable, speed limit data were associated with each of the links in the ARC TDM. This process is described in the technical memorandum: *Assignment of HPMS Functional Classification and Posted Speed Limit Attributes to the Atlanta Regional Commission Highway Network* issued concurrently with this report. Based on the availability of these data, all speed study measurements were converted to differences (positive or negative) from the posted speed limit on the sampled link for analyses of free flow speed.

## Free Flow Speed Determination

A common “rule-of-thumb” in traffic engineering for calculating “free flow” speeds calls for the use of the 85th percentile of all observations taken under low volume conditions. However, this includes conditions that were specifically excluded from collection during the speed study (e.g., accidents). To account for this exclusion, the recommended free flow speeds for each of the nine facility and area types listed above were determined by calculating the 80th percentile highest speed difference for all observations at low lane-volume conditions made during the speed study. Low lane-volumes conditions were defined as fewer than 1001 vehicles-per-lane-per-hour (vplph) for freeways and fewer than 401 vplph for non-freeways. These recommended “free flow” speed differences are given in the table below. In this table, positive (+) values represent the number of miles-per-hour that must be added to the posted speed limit to give the “free flow” speed for the link. Likewise, negative (-) values in the CBD should be subtracted from the posted speed limit to give the link “free flow “ speed for this classification. The bold lines present in the table surround the facility/area-type classifications described above and used in the analysis.

### Free Flow Speeds

**(All Values in Miles-per-Hour Difference From Posted Speed Limit)**

| Facility Type | Area Type | | | | | | |
|---|---|---|---|---|---|---|---|
| | CBD | Urban | | Suburban | | Exurban | Rural |
| | | Commercial | Residential | Commercial | Residential | | |
| Freeway | +11 | + 11 | + 11 | + 11 | + 11 | + 8 | + 8 |
| Arterial I | -8 | -1 | -1 | -1 | -1 | + 4 | + 4 |
| Arterial II | -8 | + 1 | + 1 | + 1 | + 1 | + 7 | + 7 |
| Arterial III | -8 | + 1 | + 1 | + 1 | + 1 | + 7 | + 7 |
| Collector I | -8 | 0 | 0 | 0 | 0 | + 4 | + 4 |

## *Capacity Estimates*

While the free flow speed is determined under conditions of low-volume, at various times many facilities operate at or near their ultimate capacity (i.e., maximum sustainable vehicle volume) and knowledge of these capacities is important to estimates of volume-related delay.

### Freeway Capacity

The analysis team evaluated several approaches to estimation of freeway lane capacity. All of the approaches considered produced estimated lane capacities in agreement with those recommended in the recently released Highway Capacity Manual 2000 (HCM 2000). Thus for the new emissions post-processor, the analysis team recommended the use of the HCM 2000 capacity estimates rounded to three significant digits. Following HCM recommendations, capacities were calculated using the observed "free flow" speeds with capacity reductions for the CBD due primarily to lower exit separations in this area. These values are given in the table below and cover the relatively narrow range of 2300 vplph in the CBD to 2400 vplph on rural interstates.

**Recommended Freeway Capacities**

| Area Type | Typical Free Flow Speed | HCM 2000 Capacity |
|---|---|---|
| CBD | 66 | 2300 vplph |
| Urban/Suburban | 66 | 2360 vplph |
| Rural/Exurban | 70+ | 2400 vplph |

### Capacity of Other Facilities

Although the range of observed range of volume-to-capacity ratios for non-freeway facilities was greater than that observed for freeways, the analysis team could not identify any trends that would suggest that the existing ARC capacity estimates for non-freeway facilities were systematically biased. In the absence of additional information, the analysis team recommended that the existing ARC capacity estimates be retained in the new speed post-processor.

## *Volume Delay Functions*

For emissions purposes it is necessary to estimate the average space-mean speed of a link as a function of volume. Conventionally, these estimates are made through the uses of Volume Delay Function (VDF) curves that estimate volume-related reductions in speed on the roadway network. Most functional forms of these VDF relationships produce a "speed ratio" (defined as the ratio of the average modeled speed to the estimated free-flow speed) as a function of the volume-to-capacity ratio.

### Analysis

Appropriate VDF functions were determined for each of the facility types given in the free flow speed table above. In developing the recommended VDF curves for these facilities, the analysis team compared fifteen different proposed functional forms of the VDF curve (including the current ARC curves) to the results of the speed study data. The variable parameter(s) for each of the functional forms were fit to the speed study data by a non-linear least squares fitting procedure using commercial statistical analysis software

(SigmaStat and Statistica). Each of the resulting curve fits was then tested regarding fit assumptions of normality and constant variance, its reduction of system variance ($R^2$) and other parameters. With the exception of the arterial I curves in which no fit produced a better result than the current ARC curves, the "Conical Volume Delay Function (Spiess, 1989) " was found to be the functional form that produced, on average, the results that most closely fits the speed study data.

## Conical VDF Curves

The analysis of the speed study data suggests use of conical VDF functions (Spiess, 1989) to estimate model speeds for emissions purposes. The full form of this equation is given by:

**(Link Speed)= (Free Flow Speed) * (Estimated Speed Ratio)**

In the conical VDF curves the data are fitted to a Speed Reduction Factor equation of the form:

**(Estimated Speed Ratio) =**

$$\frac{1}{\left(2+\sqrt{a^2\left(1-\left(V/C\right)^2\right)+\left(\left(2a-1\right)/\left(2a-2\right)\right)^2}-a\left(1-V/C\right)-\left(2a-1\right)/\left(2a-2\right)\right)}$$

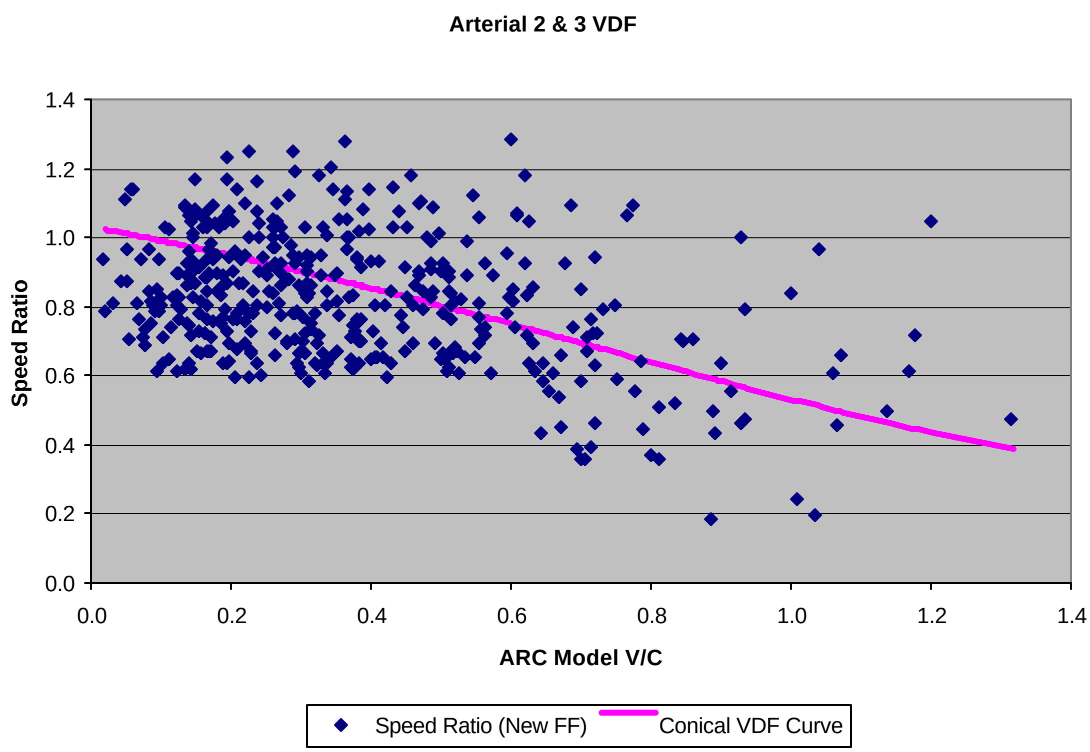
where V is the link volume (vehicles/hour), C is the link capacity (for these purposes defined as level-of-service E), and α is the adjustable facility-specific fitting parameter.

## Arterial I VDF Curve

Due to the relatively high scatter in the data and lack of sufficient data at high volume to capacity ratios, the analysis team was unable to propose a new VDF curve for the class I Arterials. The team proposed retention of the Current ARC curve with the adoption of the new free-flow speeds.

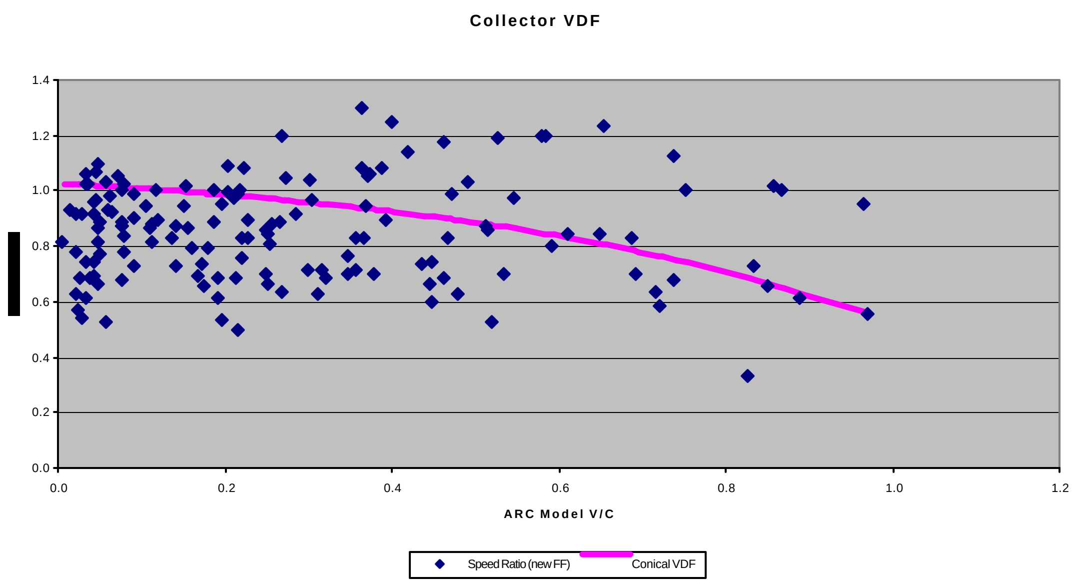
## Arterial II/III VDF Curve

For these facilities the recommended VDF function is a Conical curve with an $\alpha$ coefficient of 2.041 +/- 0.144. The fit passes both normality (P=0.679) and constant variance (P=0.831) tests and has a Pearson R of 0.247. The comparison of the speed study data with this VDF curve is given below:



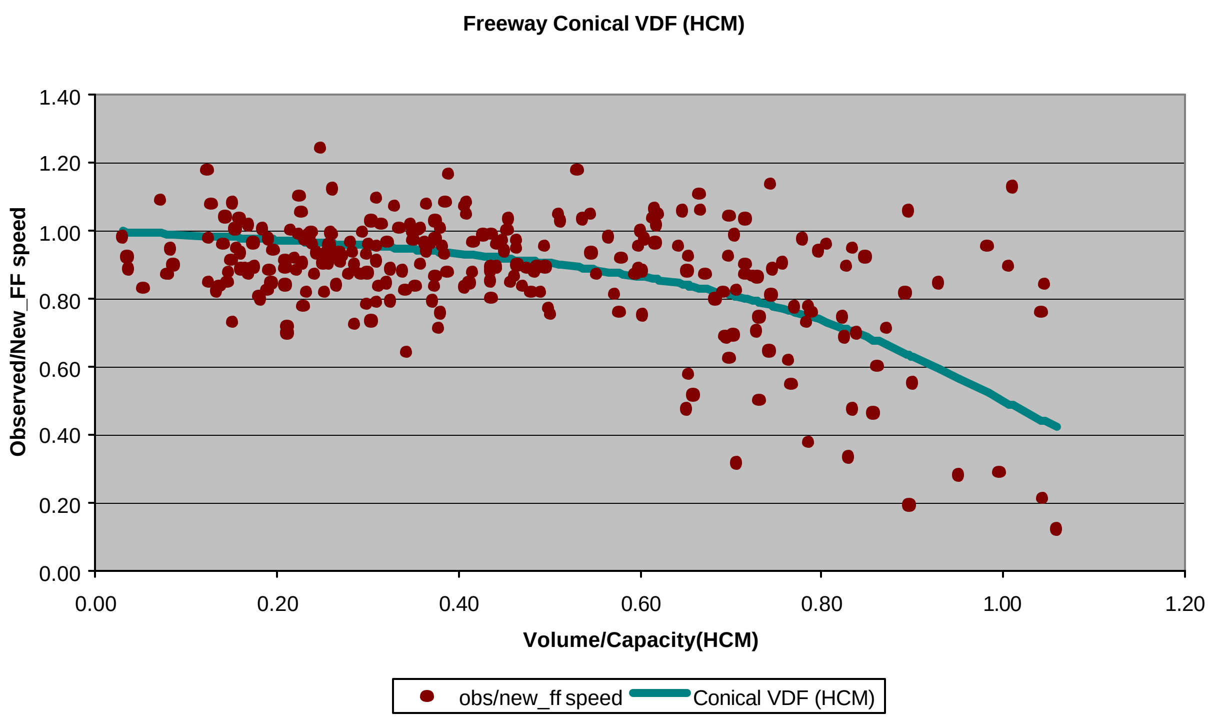

## Collector I VDF Curve

The analysis team found it useful to analyze the Class I collectors as a single classification rather than combining them with the Class III arterials, as is the case within the existing ARC model. For the collectors, the best-fit VDF is a conical curve with an $\alpha$ value of 3.583 +/- 0.782. This curve passes the statistical tests for both normality (P=0.077) and constant variance (P=0.477). For the speed study data, the fit gives a standard error of the estimate of 0.208. The comparison between this curve and the speed study data is shown below:




## Freeway VDF Curve

For the freeway facilities, the best-fit VDF curve was found to be a conical function with $\alpha$ = 5.391 +/- 0.559. The data are normally distributed (P=0.332) but did not fully meet the constant variance criteria. Nevertheless, the power of the test is high (1.00 for $\alpha_{test}$=0.05) and the Pearson R (0.439) is good considering the high variance present. The comparison between this curve and the speed study data is shown in the following figure:




## Discussion and Conclusions

The analysis team has analyzed the data from the 2000 Atlanta Speed Study and has made a series of recommendations for the implementation of and emissions speed post-processor. All data used in the calculation of the parameters discussed in this report are available on the companion CD-ROM.

We are confident that the new components in the post-processor, including adjusted "free flow" speeds, revised freeway capacities, and improved volume delay functions will result in improved estimates of Atlanta vehicle speeds for emissions modeling purposes. While significantly improved, efforts should be undertaken to continue to explore ways to improve the ability to estimate these speeds, especially to explicitly consider these needs in the traffic assignment module within the TDM. These efforts should include continued efforts to refine capacity estimates on arterials, collecting additional data on Class I Arterials and exploring technology for systematic and continuous observations of freeway speeds under a variety of conditions.